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ELECTRICAL ENGINEERING RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS

AUSTIN, TEXAS

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SUMMARY STATUS REPORT

31

for the period

1 May 1955-31 December 1955

MAY 3 1956

56AA 20280

Contract Nonr 375(07)

10 February 1956

I. INTRODUCTION

This is the first summary status report to be prepared by this Laboratory covering its research activities over the period beginning with 1 May 1955 effective date of the contract and extending to 31 December 1955. Future reports in this series will be on a semi-annual basis. These reports will be of an informal nature, written primarily to advise the sponsoring agency as to the status of the research program. Technical reports, to be given a wider distribution, will be written whenever warranted by research results.

Contract Nonr 375(07) is supported by funds made available from Evans Signal Laboratory and administered for convenience by the Office of Naval Research. The present contract provides $50,000.00 for research over a two year period. This contract is operated jointly with Contract Nonr 375(01), which for the present year has a budget of $75,000.00, two-thirds of which was supplied by the Office of Naval Research and one-third by Evans Signal Laboratory.

Contract Nonr 375(01) provides for basic propagation research in the millimeter region and for the development of the necessary components for this work in this region. Contract Nonr 375(07) was originated to provide for specialized tests designed to provide particular data required by Evans Signal Laboratory. It is largely dependent on Contract Nonr 375(01) for its source of equipment and components. This work is described in the Nonr 375(07) contract by the statement that the contractor "shall conduct studies and make measurements of radio waves being propagated over one or more fixed paths in the 2.5 to 4.5 millimeter band. Simultaneous measurements of meteorological factors shall be made."

By mutual agreement between personnel of this Laboratory and the Radar Development Branch of Evans Signal Laboratory the initial contract activity has involved

the study of the propagation of 4.3-millimeter radiation through precipitation with particular emphasis on rain attenuation observations. This report will be concerned with the equipment development and propagation measurements made to date.

II. EQUIPMENT DEVELOPMENT

A. Millimeter Equipment

A wavelength of 4.3 millimeters is being employed for the initial propagation measurements called for in this research program. This choice was dictated by the fact that Bomac magnetrons of Columbia University design operating at frequencies of about 70.0 kmc/s had been previously made available to us through Evans Signal Laboratory in connection with a millimeter propagation research program sponsored by the office of Naval Research under Contract Nonr 375(01).

1. Crystal Video Receiver

The first receiver to be constructed for making propagation measurements at this wavelength under the Nonr 375(01) contract was of the crystal video type since 4.3-millimeter local oscillators were not available at that time. A 5.4-mm Bell Telephone Laboratories experimental crystal was used as the detecting element. A series of earlier clear air propagation studies [1] had shown that this transmitter-receiver system could be used satisfactorily for distances up to 7.0 miles when conical horns fitted with hyperbolic plexiglass lens were employed as antennas. These antennas produced a beam width of about 2 degrees and a gain of approximately 41 db. While the resulting dynamic recording range and minimum detectable signal level of the receiver were such as to limit its usefulness in a comprehensive rain propagation study, it was felt that satisfactory measurements

of total attenuation could be made for a path of the order of 1000 feet.

Such an arrangement was employed for the first rain attenuation measurements under Contract Nonr 375(07) and very few if any modifications had to be made to the 4.3-millimeter equipment previously employed for the 7.0-mile propagation tests. A brief summary of the results of the first rain studies will be given in a later section.

2. Superheterodyne Receiver

Early in 1955 a QK369 reflex klystron operating at 4.3 millimeters was made available to us from Evans Signal Laboratory and construction was started on a superheterodyne receiver utilizing the klystron as a local oscillator. This receiver which has recently been completed will be utilized in the near future as one of the basic components of a 4.3 millimeter radar. This equipment will then be employed in such a manner that backscattered energy from rain can be recorded as a function of penetration distance into the rain. Total signal attenuation measurements will also be made. A corner reflector of known scattering cross-section will be used to calibrate the radar.

Several additional items of equipment are needed, however, before these backscattering studies can be made. A 4.3 millimeter test signal generator utilizing a second QK369 klystron has been completed. This can be used as a CW signal source when necessary for short paths in addition to its employment as a reference signal source. Two new conical lens antennas with lens diameters of 11 inches are about 50% complete. These antennas will have a gain of 43 db and produce a beam width of 1.1°. The necessary sweeping circuits for obtaining the backscatter-distance function are complete.

3. Performance Characteristics of the 4.3 mm Bomac Magnetrons

It was found in order to maintain a radio frequency pulse length of 0.25 microseconds as operating time accumulated, that progressively less external

power to the heater element of the magnetron was required. This condition eventually reached a point in the first two magnetrons received, where external control of the temperature of the cathode of the magnetron was lost. Only very short pulses of radio frequency power were then obtained, making the magnetrons useless. The third and fourth magnetrons received, which were about 18 months old, could not be made to produce a 0.25 micro second pulse. This deterioration apparently occurs even when the units are on the shelf leading one to suspect a type of mechanical instability.

While it was possible by very careful control and adjustment to obtain readable and reasonably accurate 4.3 mm signal levels during the first rain propagation study, deterioration of the magnetron signal source has progressed to the extent that none of the magnetrons now on hand can be used for future measurements. Accordingly the 4.3 millimeter test signal generator is now being used as a transmitter and the crystal video receiver replaced with the superheterodyne receiver in order to complete the rain attenuation measurements. While efforts will be made to see if backscattering observations can also be made with this installation, the possibilities of success are not too high.

B. Meteorological Equipment

The meteorological phase of this millimeter wave propagation study has been concerned to date with the determination of the rainfall rate and drop size distribution existing over the radio path during the propagation observation period. The following standard installations are now available for these measurements:

1. Four standard tipping bucket rain gages are located at uniform spacing 200 feet along the radio path. Following the first attenuation measurements on 30 November 1955, the sensitivity of these instruments was increased by doubling the rainfall catch area so that rainfall amounts in 0.05 of an inch are now being recorded.

2. A weighing type recording rain gage having an original capacity of 12 inches and a chart revolution time of 6 hours has been located near the center of the radio path in order to provide a permanent record of rainfall amount. The sensitivity of this unit has also recently been increased, the catch area being quadrupled. Neither of the above installations, however, are entirely satisfactory in determining a time variation of rainfall rate over short periods, the tipping buckets because of the non-continuous nature of the record and the weighing gage because of the coarseness of the time scale on the instrument. An instrument was desired which would give a continuous record of rainfall amount over a time scale which would permit essentially point by point comparison with the normal three minute millimeter signal strength recording. An experimental model of a continuous wire water level recorder has been devised which it is believed will give satisfactory results. This instrument consists essentially of a pair of separated conducting wires mounted axially along a plastic rain collecting cylinder. A known concentration salt solution runs into this cylinder from a larger source reservoir. This salt solution is displaced in equal amount by rain water entering the top of the reservoir. The magnitude of the dc current flowing from one wire to the other is then a function of the salt water level in the cylindrical tube and thus a measure of the rainfall amount. By using a rectangular coordinate recording meter, it is a simple matter to evaluate rainfall rates from the slope of the depth-time curve. Changes in rainfall amount as low as 0.002 inches can be easily detected with time resolution down to about 1 second. One of these instruments is now in use and a second will be ready in the near future.

The drop size distribution measurements are being made using the dye coated filter paper technique. An earlier test wherein drops of water of known size fell at terminal velocity on the filter paper had provided the necessary calibration over

a drop diameter range from about 0.25 to 4.0 millimeters. The filtered paper housing is watertight and an exposure of any desired time can be made by the manual movement of a sliding top. Two of these units are now available for obtaining data along the radio path although only one was in use during the 30 November 1955 measurement period.

III. PROJECT DATA AND PRELIMINARY RESULTS

A. 8 November 1955

The first measurable precipitation occurring after the 1000 foot propagation path was ready for operation occurred on 8 November 1955. As a result, however, of a rather freakish weather situation, the precipitation fell in the form of snow rather than rain. At maximum density snowfall, visibility was reduced to about 2000 feet with a corresponding loss of millimeter signal of about 0.3 db below free space. Quantitative correlating meteorological measurements were not available.

B. 30 November 1955

This situation produced the only available set of corresponding meteorological and 4.3 millimeter signal level data obtained to date. Five three minute radio runs were obtained during this period. Although data from three tipping bucket gages were available throughout the measurement period, the intermittent nature of the precipitation and the use of the original 0.01 inch steps in the gage made it very difficult to evaluate accurate rainfall rates over the desired short time intervals. Accordingly the dye coated filter paper samples were also used to compute a rainfall rate which was averaged over the 3-20 second sampling time required to obtain the proper density of water spots.

Two methods were used to determine a theoretical total attenuation from the drop size data to compare with the measured radio signal loss. In both of these

cases, the proceedure involved the computation of an integral [2],

$$\gamma = 434\int_0^\infty n(a)\, Q(a,\lambda)\,da \qquad (1)$$

where γ is the computed total attenuator in db/km for a drop size distribution n(a)da which gives the number of drops per cubic meter with radius a in the range da. $Q(a,\lambda)$ is the total cross section and is a function of the drop radius and wavelength, λ. The total cross section can be interpreted as the sum of a scattering and an absorption cross section.

Values of this total cross section have been computed from rather complex infinite series expansions by Ryde and Ryde covering the range of λ from 0.3 to 10.0 centimeters and for drop radii from 0.025 to 0.325 centimeters. Value of $Q(a,\lambda)$ for 0.43 centimeters were obtained by interpolation from these computations. The two methods used in obtaining a theoretical γ consisted of (a) using values which had been previously computed by Ryde and Ryde in which it is assumed that the drop size distribution is a unique function of rainfall rate, and (b) approximating the integral (1) by a finite sum of terms using the actually observed n(a) for each sample. The results of both of these computations are shown in Figures 1 and 2 where observed attenuations are plotted as a function of computed values. These two figures show remarkably little scatter of points and by their similarity imply that the computed attenuation coefficient are not overly sensitive to variations in the drop size distributions. Actually the average n(a) values of Laws and Parsons do agree in general with those observed here although there are significant variations. A comparison of these observed and computed distributions for several of the runs is given in Figures 3 and 4. It should be noted that a value, m(a), the fraction of the total volume of water striking the ground due to drops of radius, a, is plotted here for convenience rather than, n(a). The relationship between the

two distributions is as follows

$$m(a) = \frac{15.1\ n(a)\ v(a)\ a^3}{p} \qquad (2)$$

where v(a) is the terminal velocity of the drop and p is the precipitation rate in millimeters per hour.

Although these first results are quite encouraging, one or two factors must be kept in mind. First of all there is an uncertainty in the radio data of about ± 0.1 db and great care had to be taken to assure this relatively low figure. The meteorological data, moreover, is subject to a good deal of interpretation particularly since for all practical purposes only the one set of drop size distributions were used in the analysis. An improved dye and sampling technique together with a second unit should provide more reliable data. The rainfall rate data obtained with the continuous wire rain gage will also serve as an independent measure of the correctness of the drop size measurements. Additional data are needed, too, at the higher attenuation rates before full assurance can be placed on the first results. It is hoped that one additional good rainfall study will provide the necessary additional data to put the results on a firm footing. When this has been obtained, a technical report covering this phase of the research will be prepared.

V. FUTURE ACTIVITIES

These will consist of additional total attenuation and rain characteristic measurements through rainfall over the 1000 foot path using a CW klystron transmitting source. Backscatter measurements will be made if possible but it is felt that these will not be feasible until new 4.3 mm magnetrons are obtained. Efforts will be made to acquire these as soon as possible.

Certain initial propagation tests are also scheduled in the near future at 3.3 millimeters. While the greater part of the developmental work and measurement at this new wavelength comes under contract Nonr 375(01) rain and fog propagation studies will be made as soon as possible.

REFERENCES

1. Tolbert, C. W., et al, "Propagation of 4.3 Millimeter Radio Waves on 3.5- and 7.0-Mile Paths," Electrical Engineering Research Laboratory, Report No. 73, 6 August 1954.
2. Kerr, D. E., "Propagation of Short Radio Waves," Vol. 13 M.I.T. Radiation Laboratory Series, McGraw-Hill Book Company, Inc., pp. 671-685.

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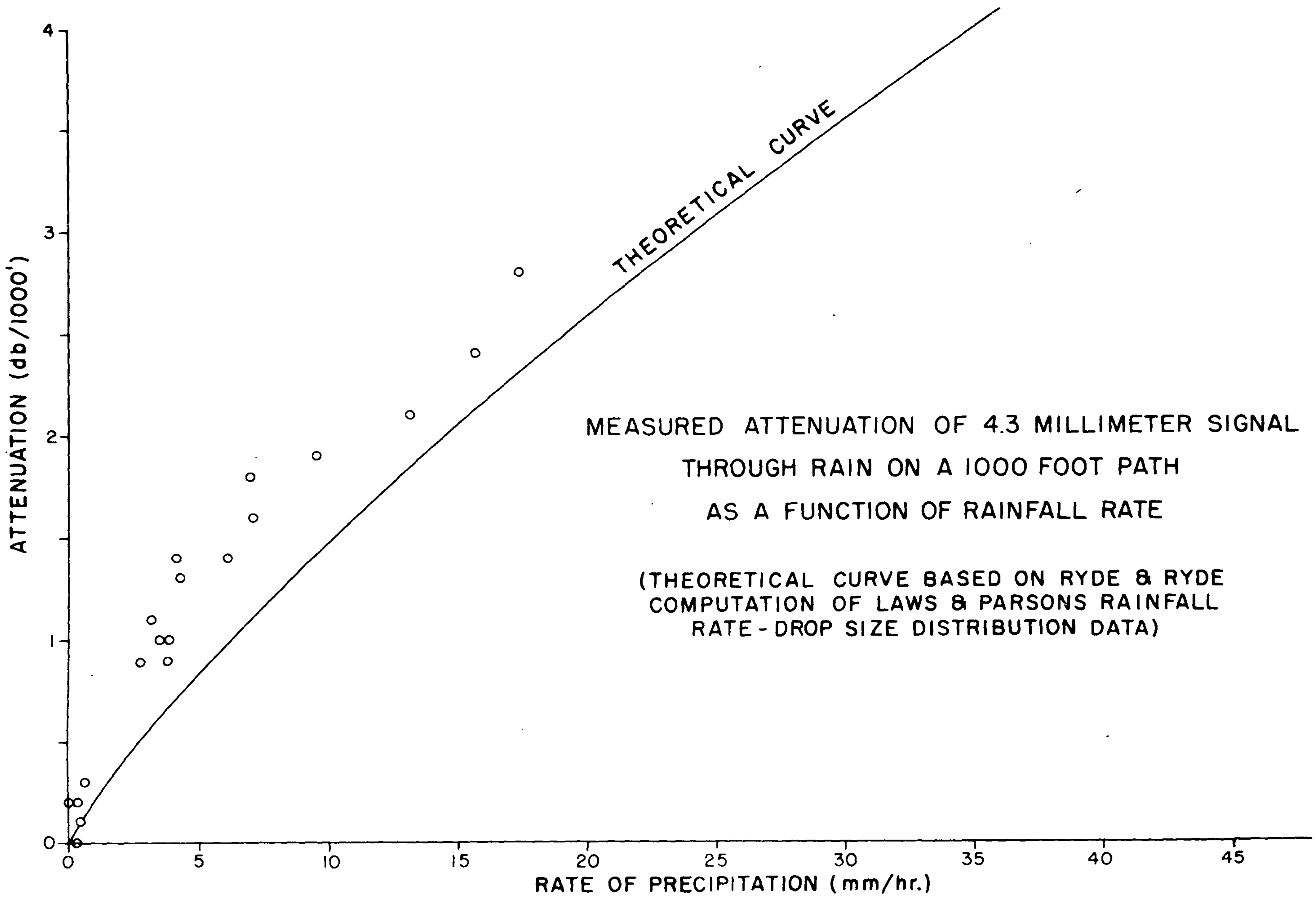


THEORETICAL CURVE
MEASURED ATTENUATION OF 4.3 MILLIMETER SIGNAL
THROUGH RAIN ON A 1000 FOOT PATH
AS A FUNCTION OF RAINFALL RATE
(THEORETICAL CURVE BASED ON RYDE & RYDE
COMPUTATION OF LAWS & PARSONS RAINFALL
RATE-DROP SIZE DISTRIBUTION DATA)
ATTENUATION (db/1000')
0
1
2
3
4
0
5
10
15
20
25
30
35
40
45
RATE OF PRECIPITATION (mm/hr.)

FIG. 1

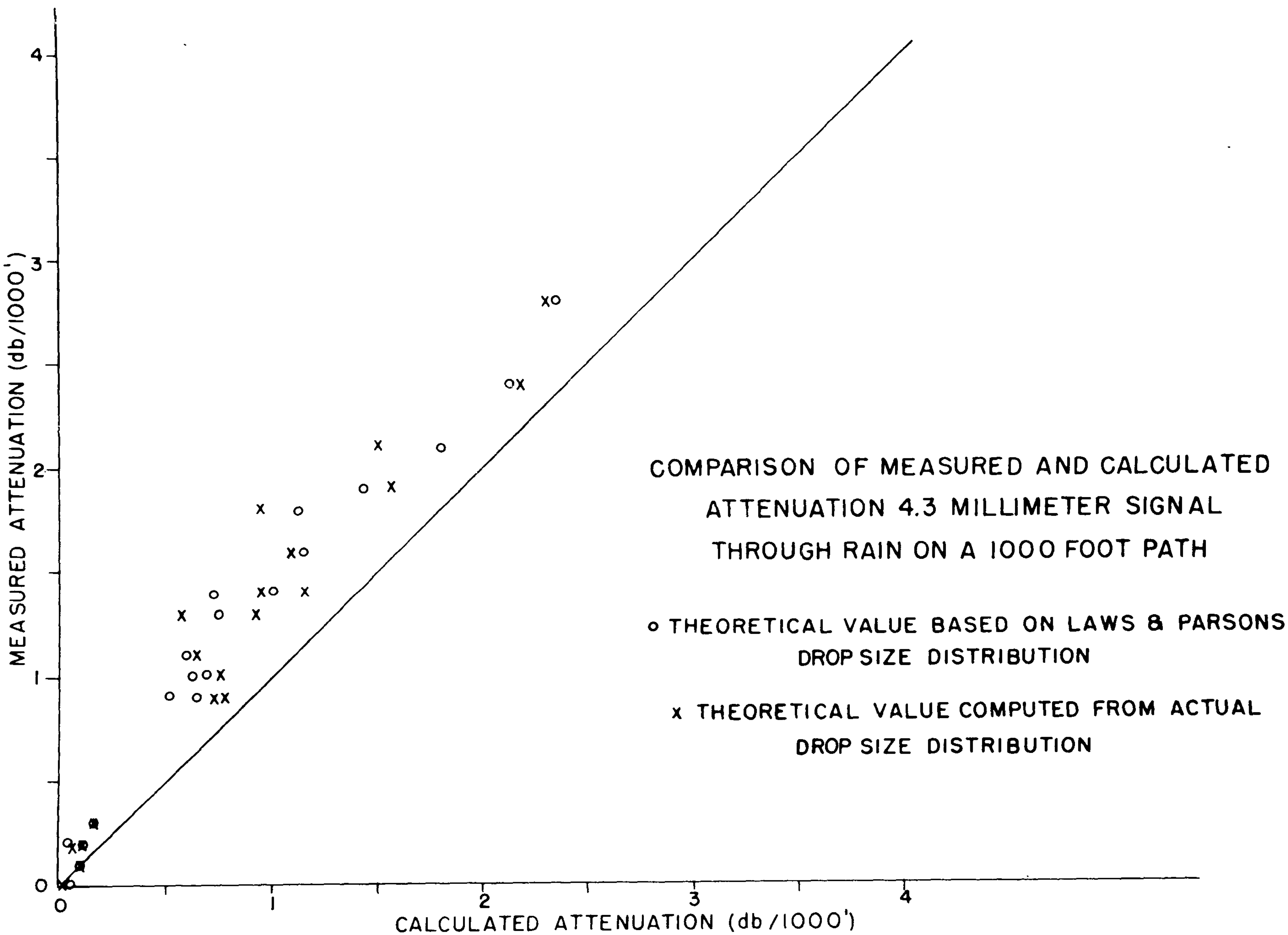
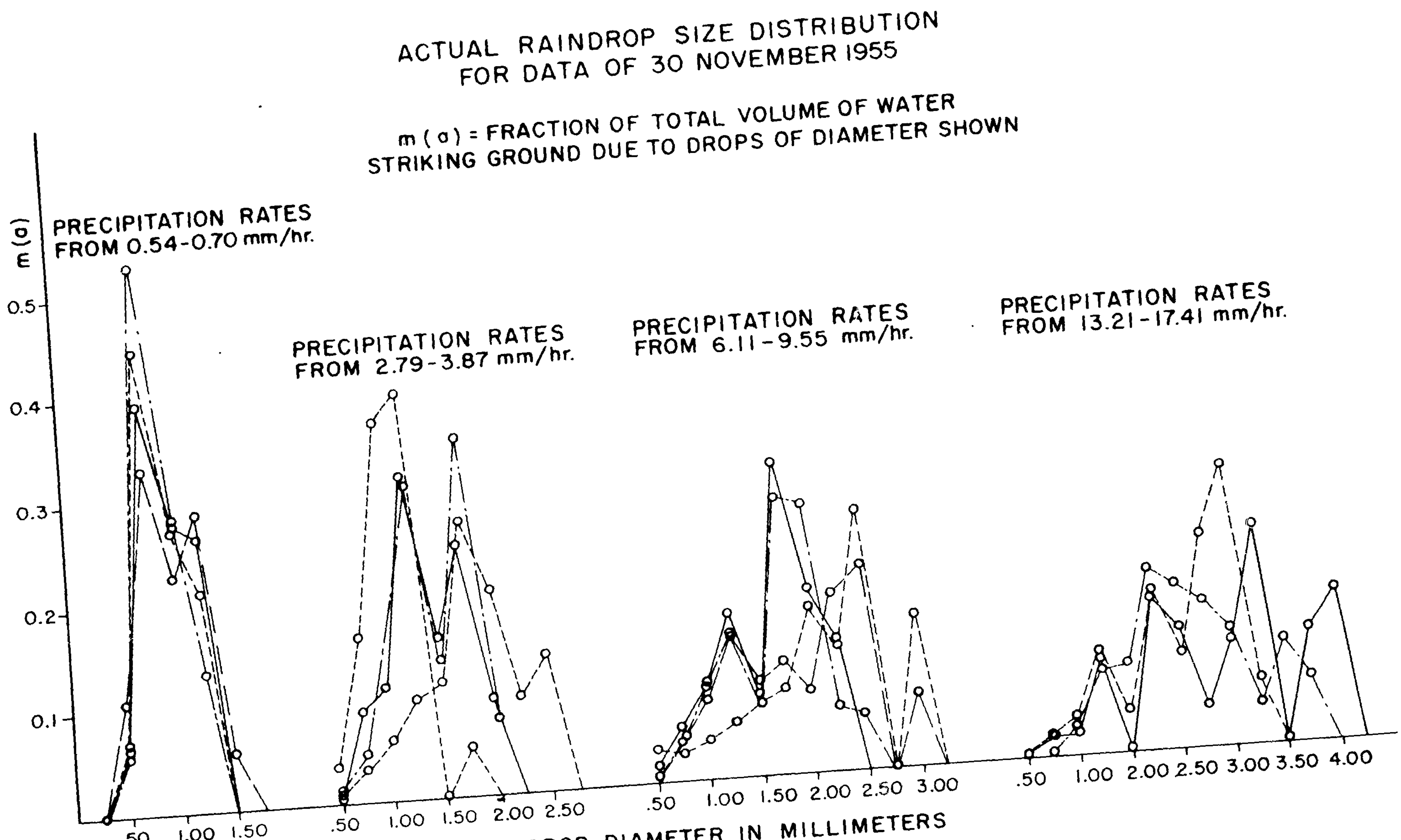

MEASURED ATTENUATION (db/1000')
0
1
2
3
4
CALCULATED ATTENUATION (db/1000')
COMPARISON OF MEASURED AND CALCULATED
ATTENUATION 4.3 MILLIMETER SIGNAL
THROUGH RAIN ON A 1000 FOOT PATH
o THEORETICAL VALUE BASED ON LAWS & PARSONS
DROP SIZE DISTRIBUTION
x THEORETICAL VALUE COMPUTED FROM ACTUAL
DROP SIZE DISTRIBUTION

FIG. 2



ACTUAL RAINDROP SIZE DISTRIBUTION
FOR DATA OF 30 NOVEMBER 1955
m (a) = FRACTION OF TOTAL VOLUME OF WATER
STRIKING GROUND DUE TO DROPS OF DIAMETER SHOWN
m (a)
0.5
0.4
0.3
0.2
0.1
PRECIPITATION RATES
FROM 0.54-0.70 mm/hr.
PRECIPITATION RATES
FROM 2.79-3.87 mm/hr.
PRECIPITATION RATES
FROM 6.11-9.55 mm/hr.
PRECIPITATION RATES
FROM 13.21-17.41 mm/hr.
.50 1.00 1.50
.50 1.00 1.50 2.00 2.50
.50 1.00 1.50 2.00 2.50 3.00
.50 1.00 2.00 2.50 3.00 3.50 4.00
DROP DIAMETER IN MILLIMETERS

FIG. 3

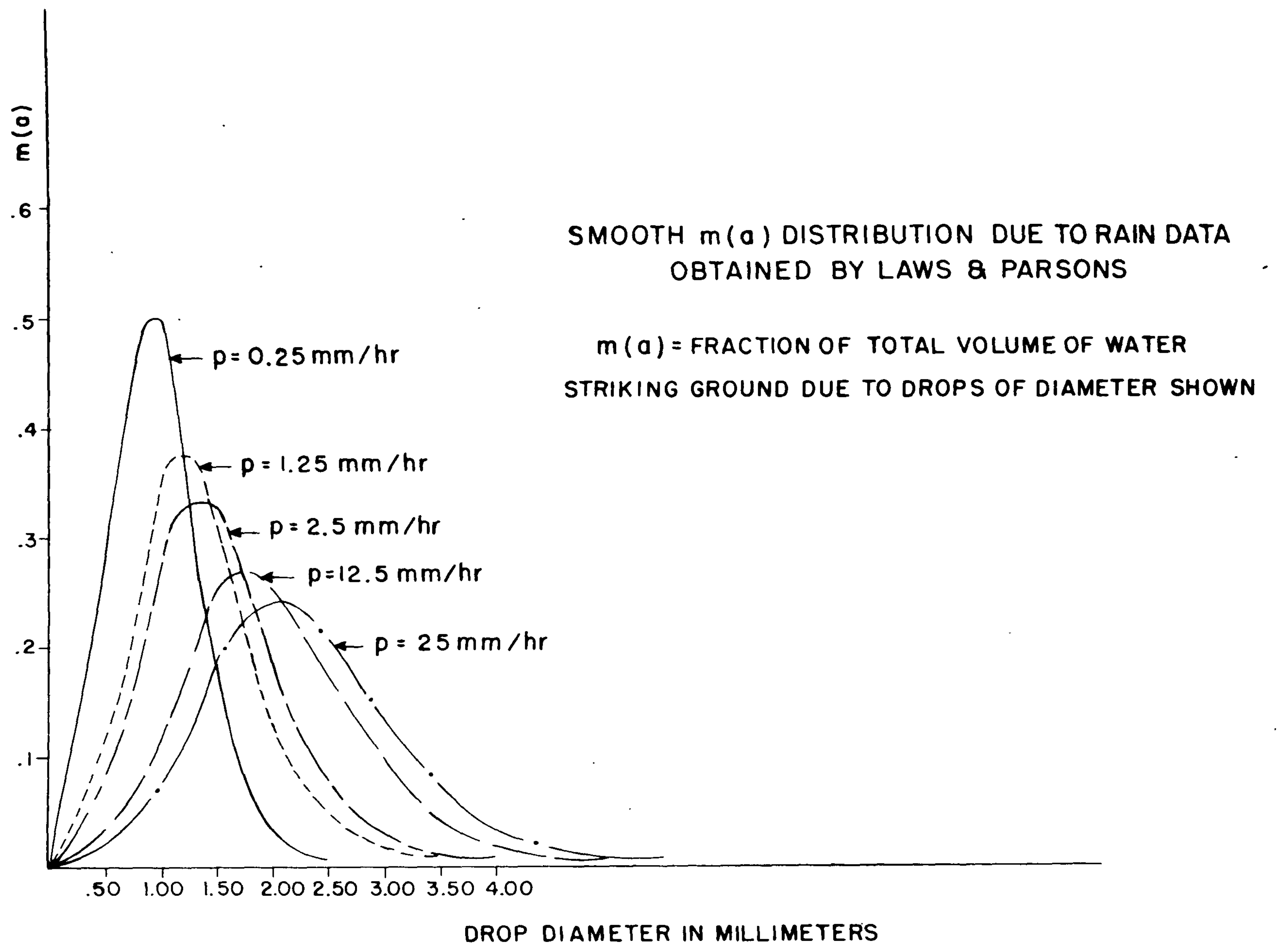

m(a)
.6
.5
.4
.3
.2
.1
p = 0.25 mm/hr
p = 1.25 mm/hr
p = 2.5 mm/hr
p = 12.5 mm/hr
p = 25 mm/hr
.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00
SMOOTH m(a) DISTRIBUTION DUE TO RAIN DATA
OBTAINED BY LAWS & PARSONS
m(a) = FRACTION OF TOTAL VOLUME OF WATER
STRIKING GROUND DUE TO DROPS OF DIAMETER SHOWN
DROP DIAMETER IN MILLIMETERS

FIG. 4